Florida Academy of Sciences

Fast detection of high-Z materials in a Muon Tomography Station (MTS)

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Outline

- Background
- Motivation
- Initial approach/results
- New approach/results
- Conclusion
- Future steps

Tomography

- Creating an image of an object through processing the deflection of rays that pass through it
  - Can be done with X-rays, gamma rays, electrons, etc.
- Shielding makes this difficult, but can be countered by using muons

Muon Tomography

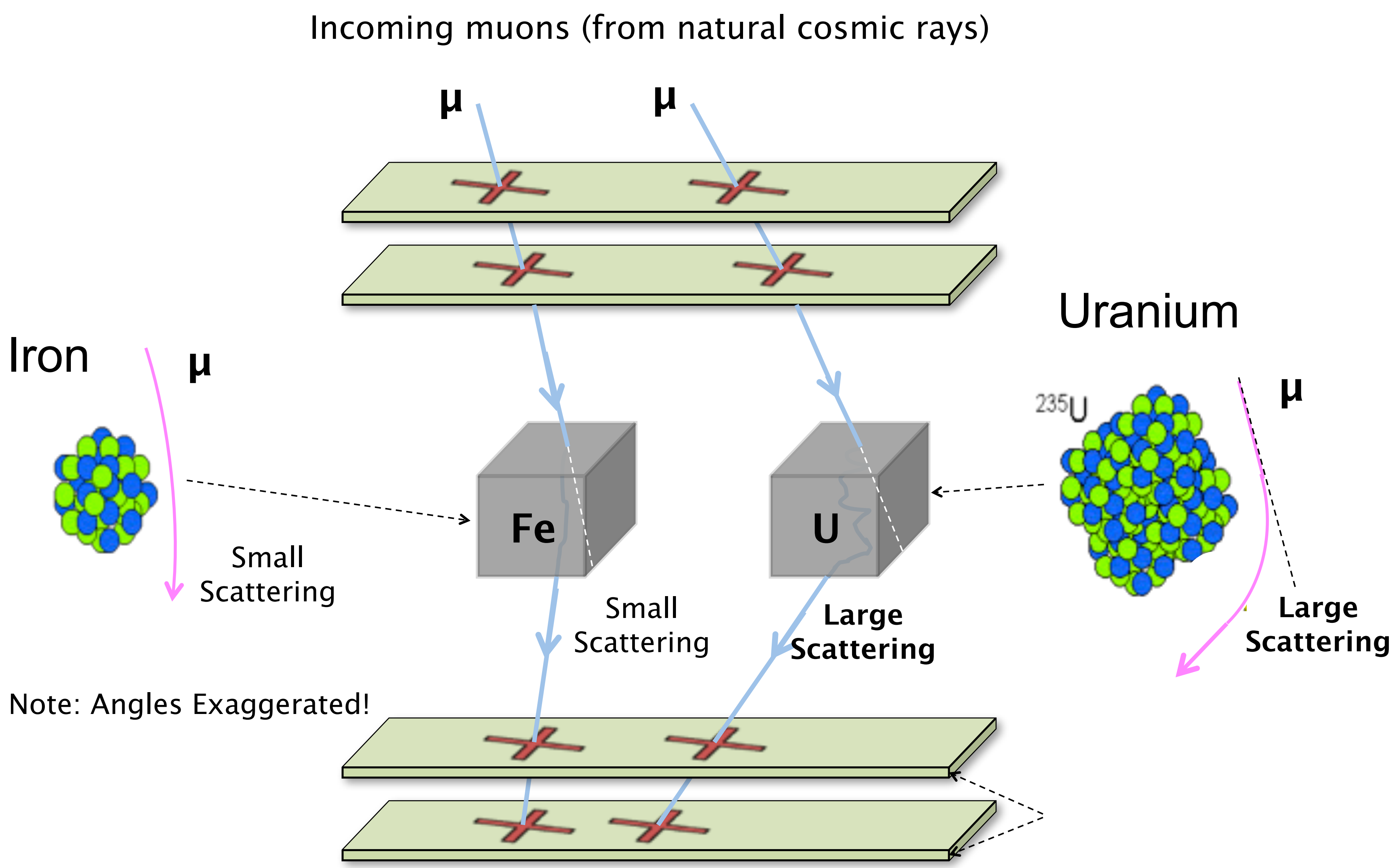
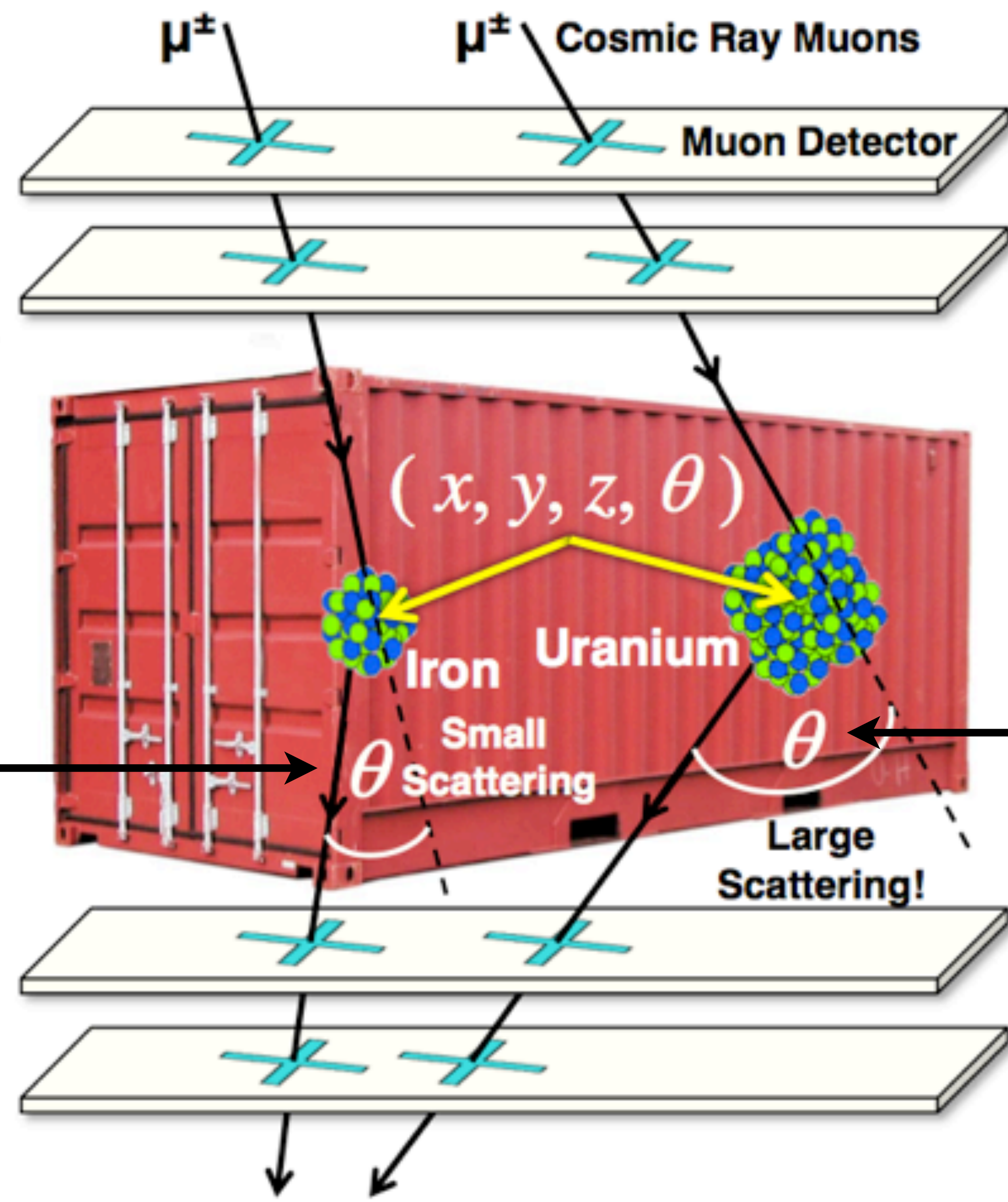


Figure by Ben Locke, Florida Tech High Energy Physics Group A

Point of Closest Approach (POCA) Angle

Small POCA angle



Large POCA angle

Figure by Ben Locke, Florida Tech High Energy Physics Group A

Muon Tomography Station (MTS) at Florida Tech

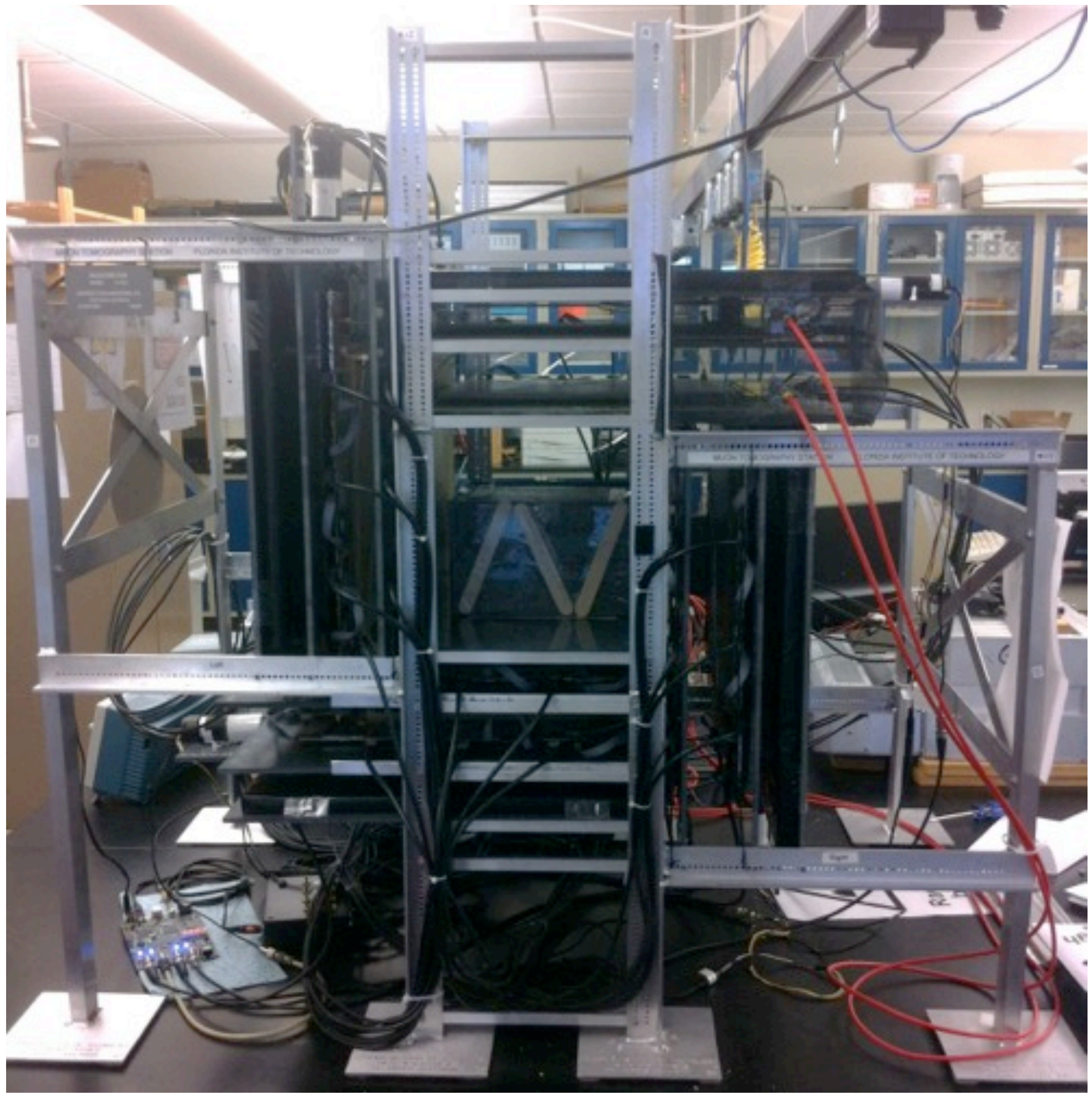


Photo by Mike Staib, Florida Tech High Energy Physics Group A

Muon Tomography Station (MTS) at Florida Tech

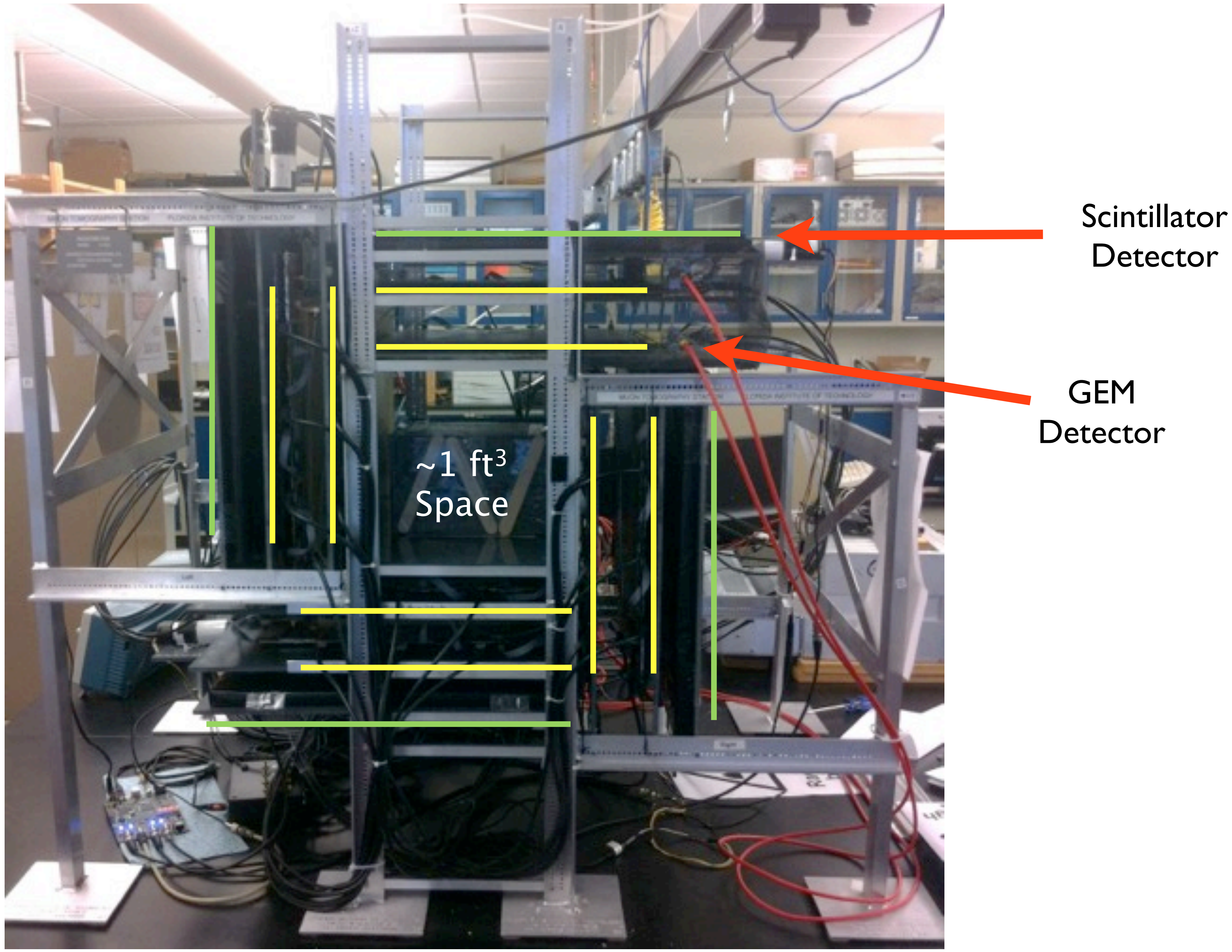


Photo by Mike Staib, Florida Tech High Energy Physics Group A

Scenarios

- Five target - contains blocks of lead, tungsten, depleted uranium, tin, and iron
- Lead shield - five target scenario plus a tantalum block and surrounded by lead
- Brass shield - depleted uranium surrounded by brass
- Empty - nothing in the station

Five target

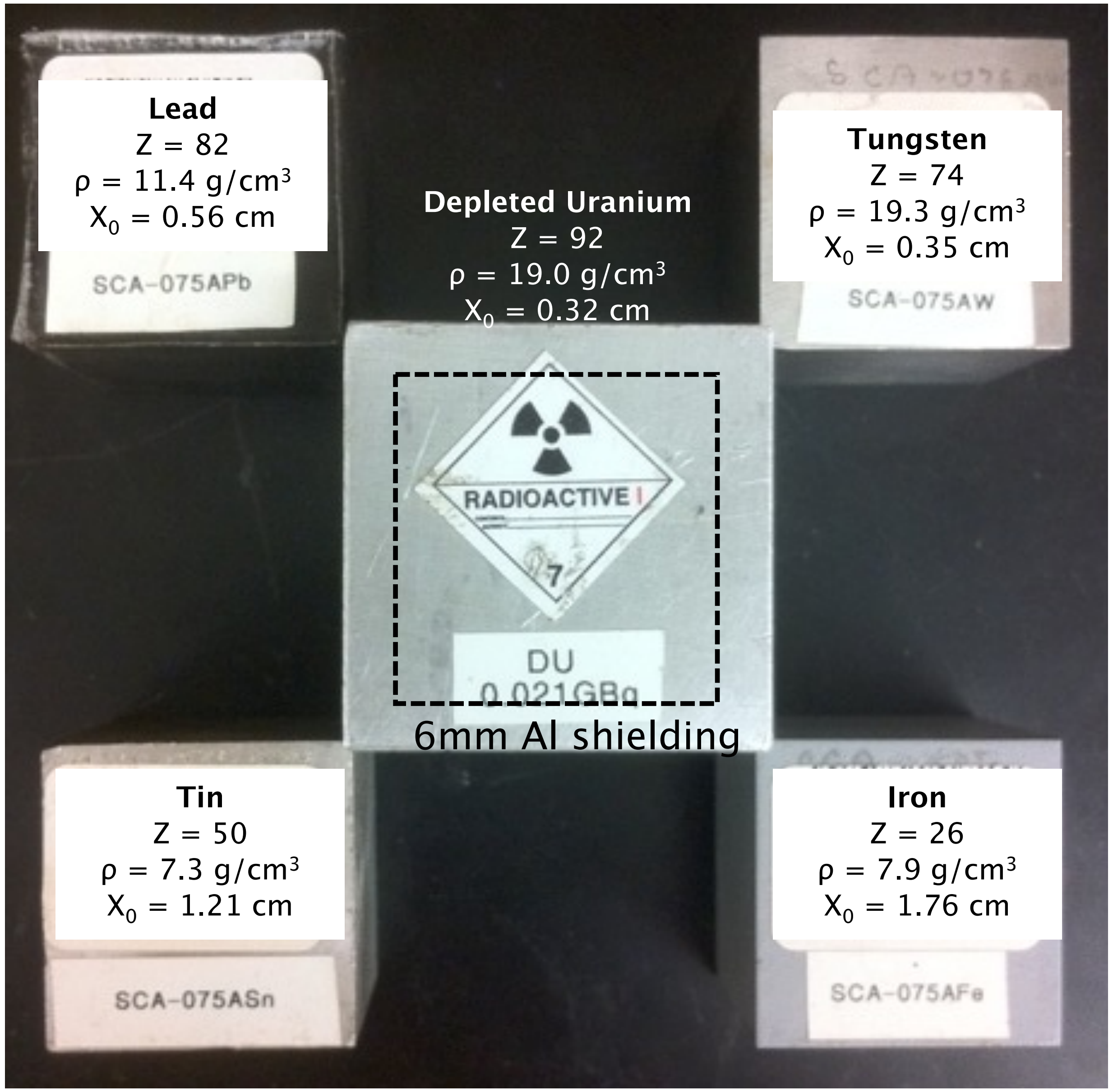
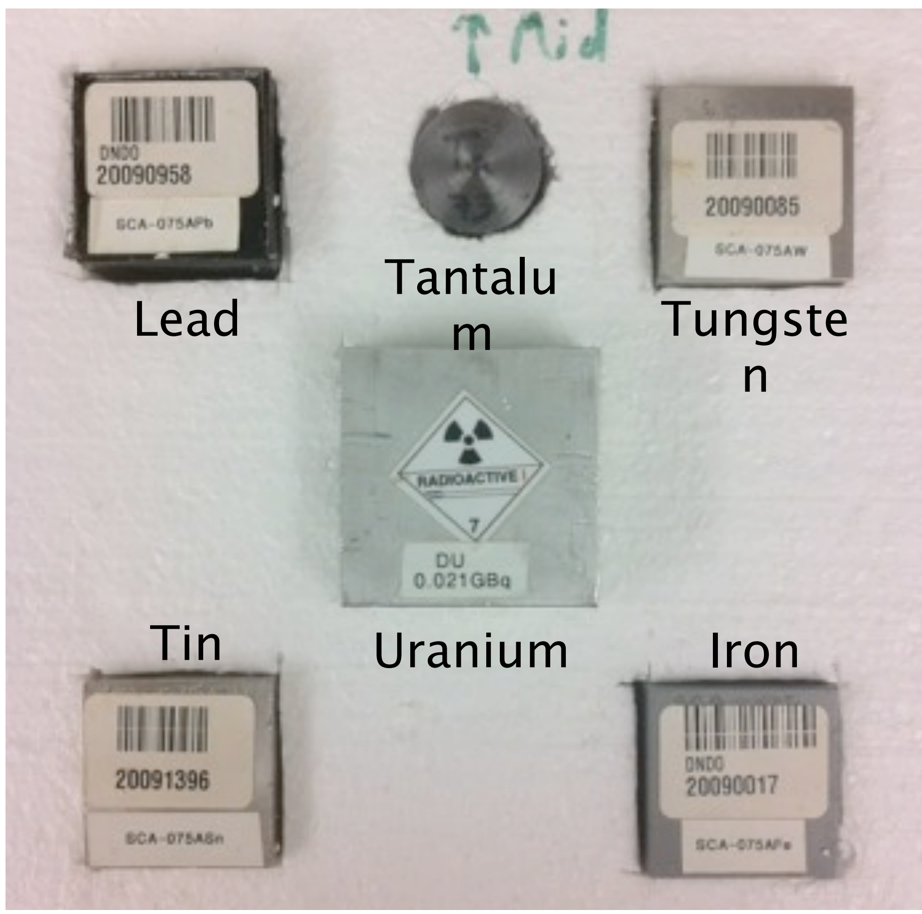


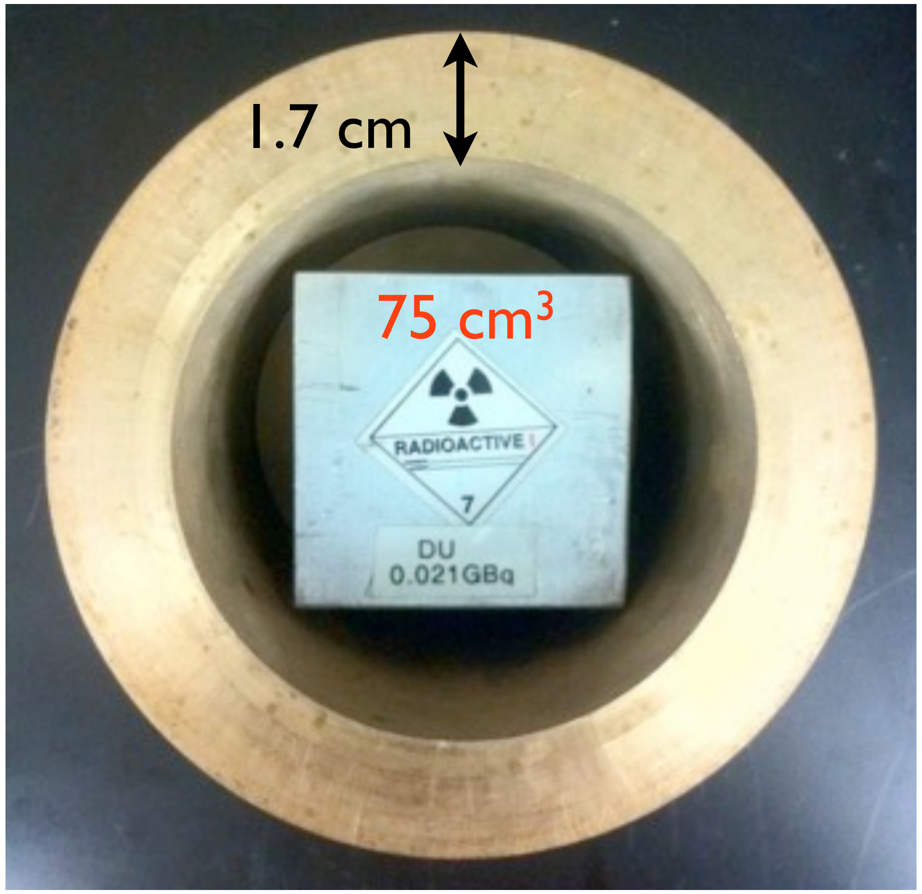
Photo by Mike Staib, Florida Tech High Energy Physics Group A

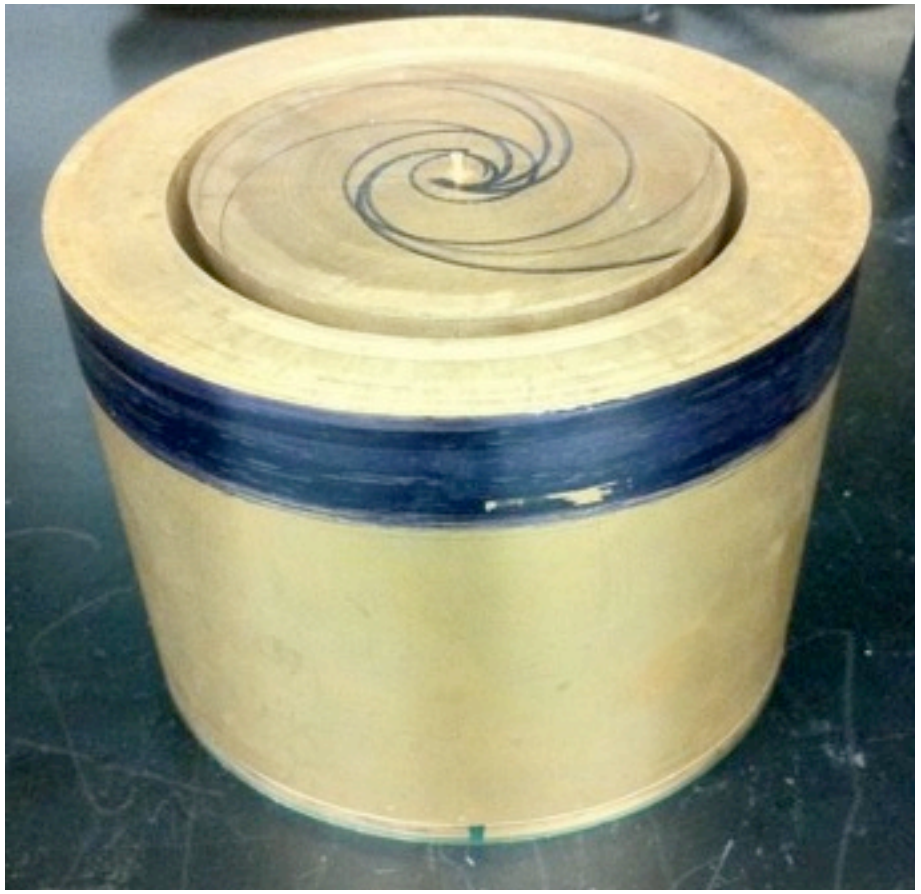
Lead shield



Photos by Mike Staib, Florida Tech High Energy Physics Group A

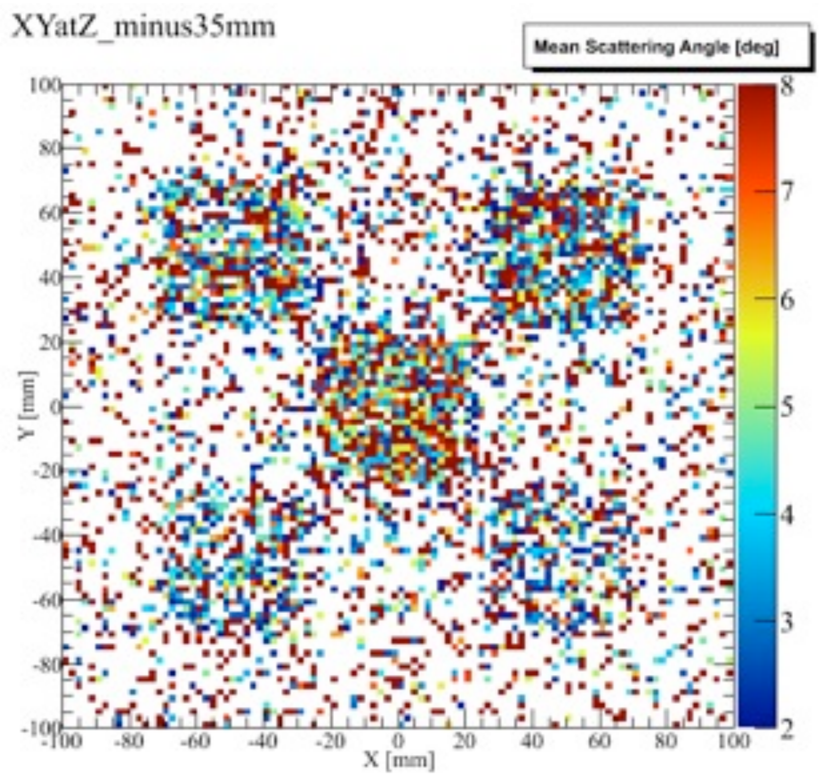
Brass Shield



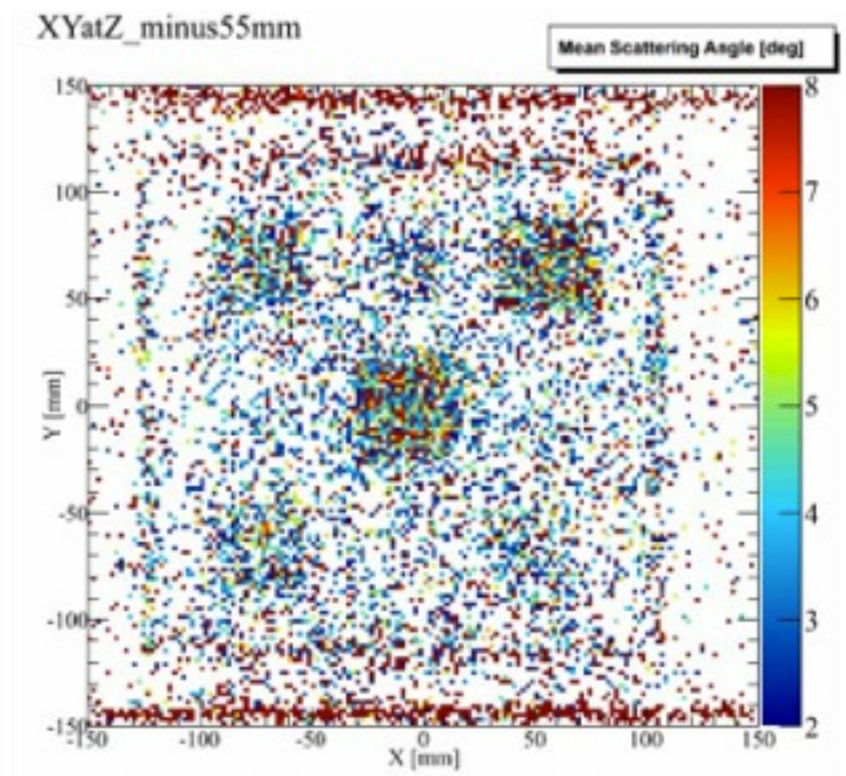


Photos by Mike Staib, Florida Tech High Energy Physics Group A

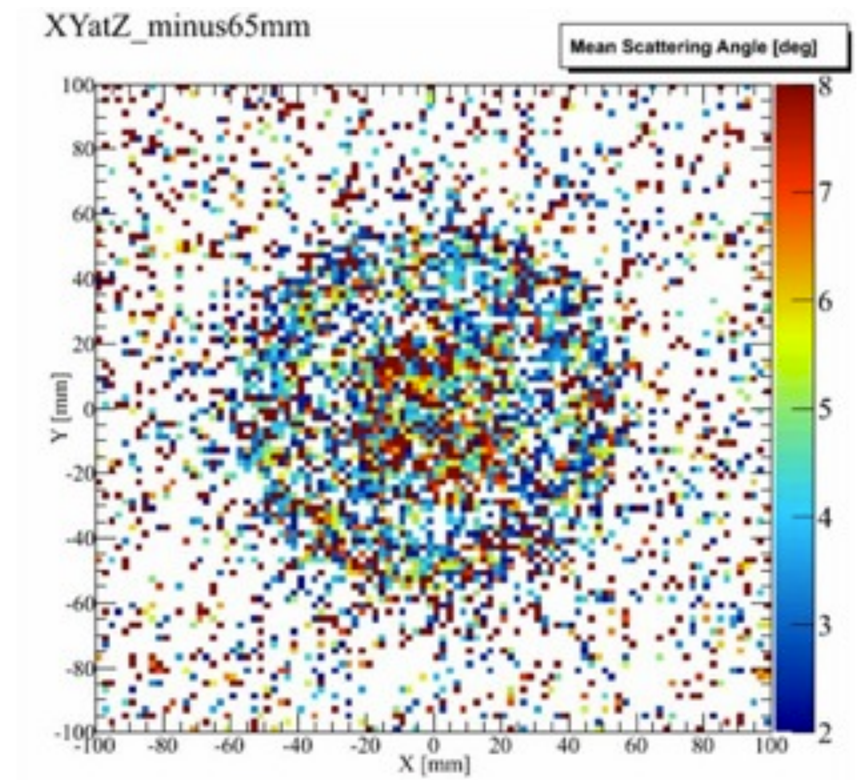
Reconstruction



Five target



Lead shield



Brass shield

A slice of three scenarios viewed from above
Each came from a data set of over 100,000 points

Figures by Mike Staib, Florida Tech High Energy Physics Group A

Post-processing

High-Z materials appear much denser

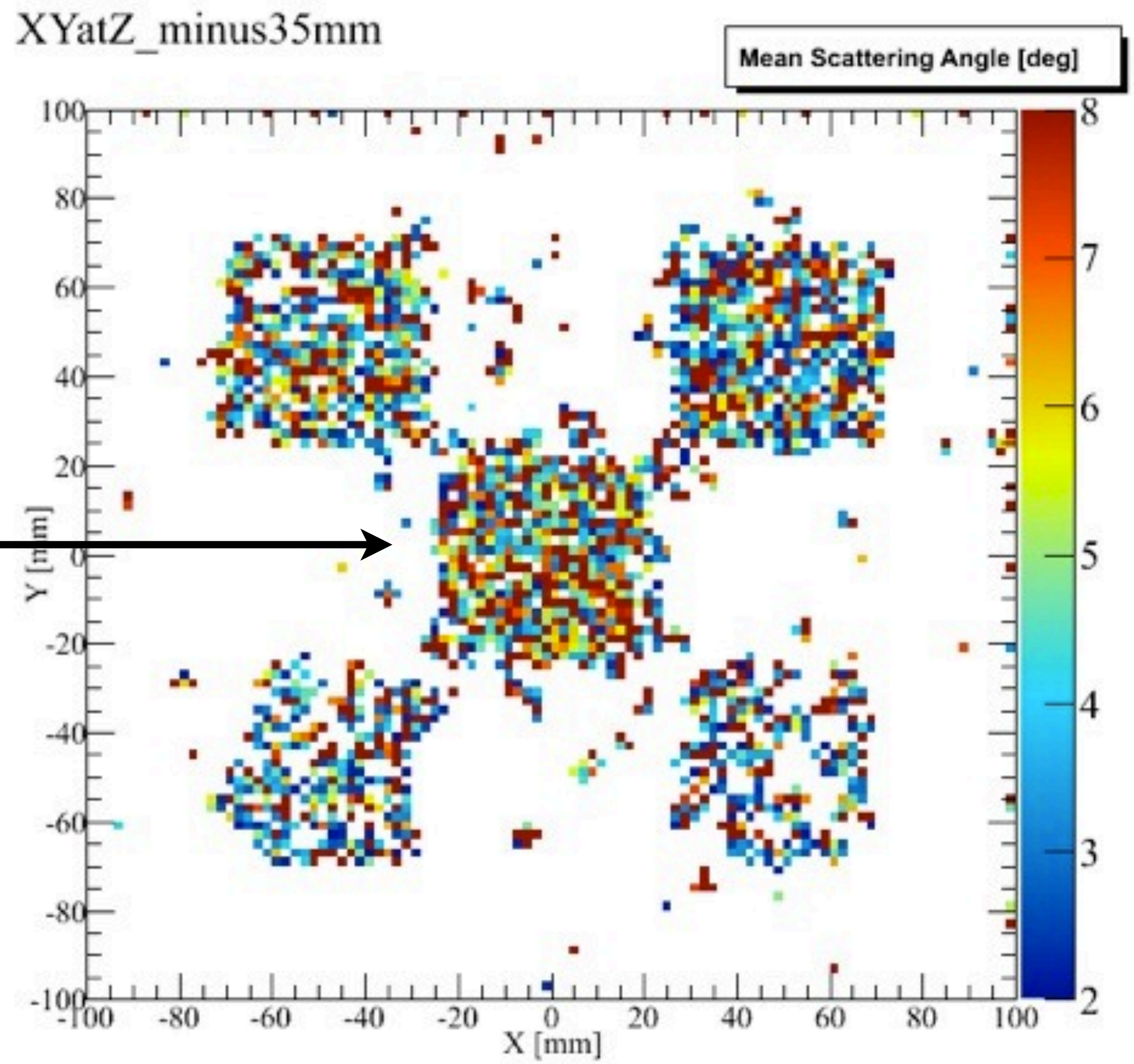


Figure by Mike Staib, Florida Tech High Energy Physics Group A

Pb 82		W 74
	U 92	
Sn 50		Fe 26

(chemical symbols and atomic numbers for reference)

Motivation

- Muon Tomography Station (MTS) can image objects very well
- Can take hours/days to gather enough data to produce a clear image
  - Muons occur naturally at 10/sec/m^2
  - MTS gets roughly 100 "good" events/minute
- Impractical for detecting potentially dangerous high-Z materials in cargo

Objective

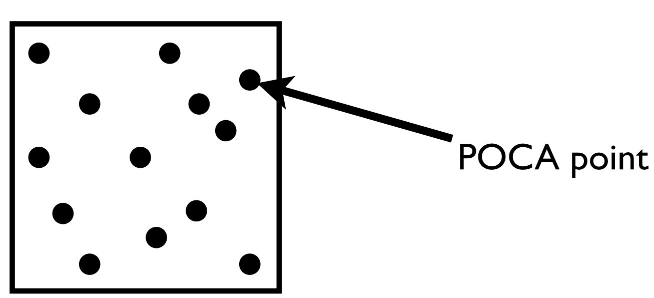
- Investigate methods for *fast detection* of high-Z materials using POCA data statistics
- Find the lowest number of points necessary
- Location/shape not as important (for now)
- Should be able to run while the station is collecting data

Small amount of POCA data → "n% chance of containing high-Z material" → "might want to check points p1, p2, p3, etc"

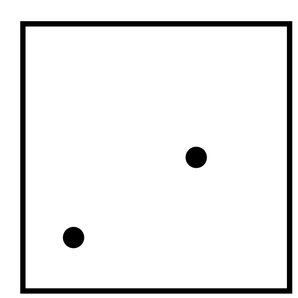
Initial Approach

- Use POCA point density
- High-Z materials should have a higher density of POCA points
- A region containing a high number of POCA points will be suspicious

In theory:



Area that overlaps a high-Z material

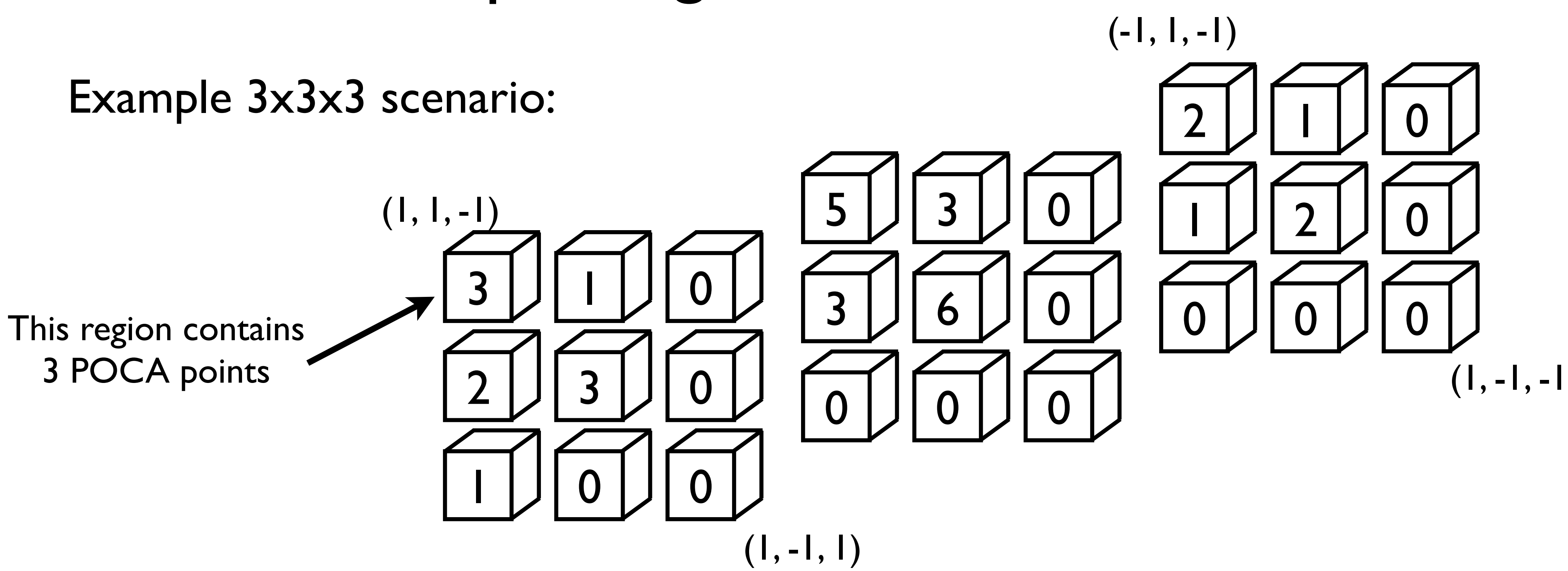


Area that overlaps empty space or low-Z material

Initial Approach

- Divide the space into a 3D grid
- Count the number of POCA points in each box
- A box with a high number of hits suggests that it overlaps a high-Z material

Example 3x3x3 scenario:



Initial Findings

5,000 events (~1.5 hrs), box length = 20 mm

	Highest count	Location of highest count (mm)	Avg scattering angle (degrees)
Five target	56	-20, -20, -40	13.30
Lead shield	25	60, 0, -60	13.72
Brass shield	29	-20, 0, -60	14.27
Empty	19	40, -20, -100	9.21

Initial Findings

1,000 events (~20 mins), box length = 20 mm

	Highest count	Location of highest count (mm)	Avg scattering angle (degrees)
Five target	13	-20, -20, -60	13.04
Lead shield	7	0, -40, -20	12.80
Brass shield	7	40, -100, -100	13.76
Empty	11	40, -100, -100	8.65

Initial Findings

500 events (~5 mins), box length = 20 mm

	Highest count	Location of highest count (mm)	Avg scattering angle (degrees)
Five target	6	-60, 60, -60	12.87
Lead shield	5	-20, 0, -60	13.19
Brass shield	5	0, 0, -60	13.21
Empty	8	40, -100, -100	8.88

Problem

- Location was usually way off
- Realized there was a bias in the station
- Will always find the most events at the center

MTS Bias

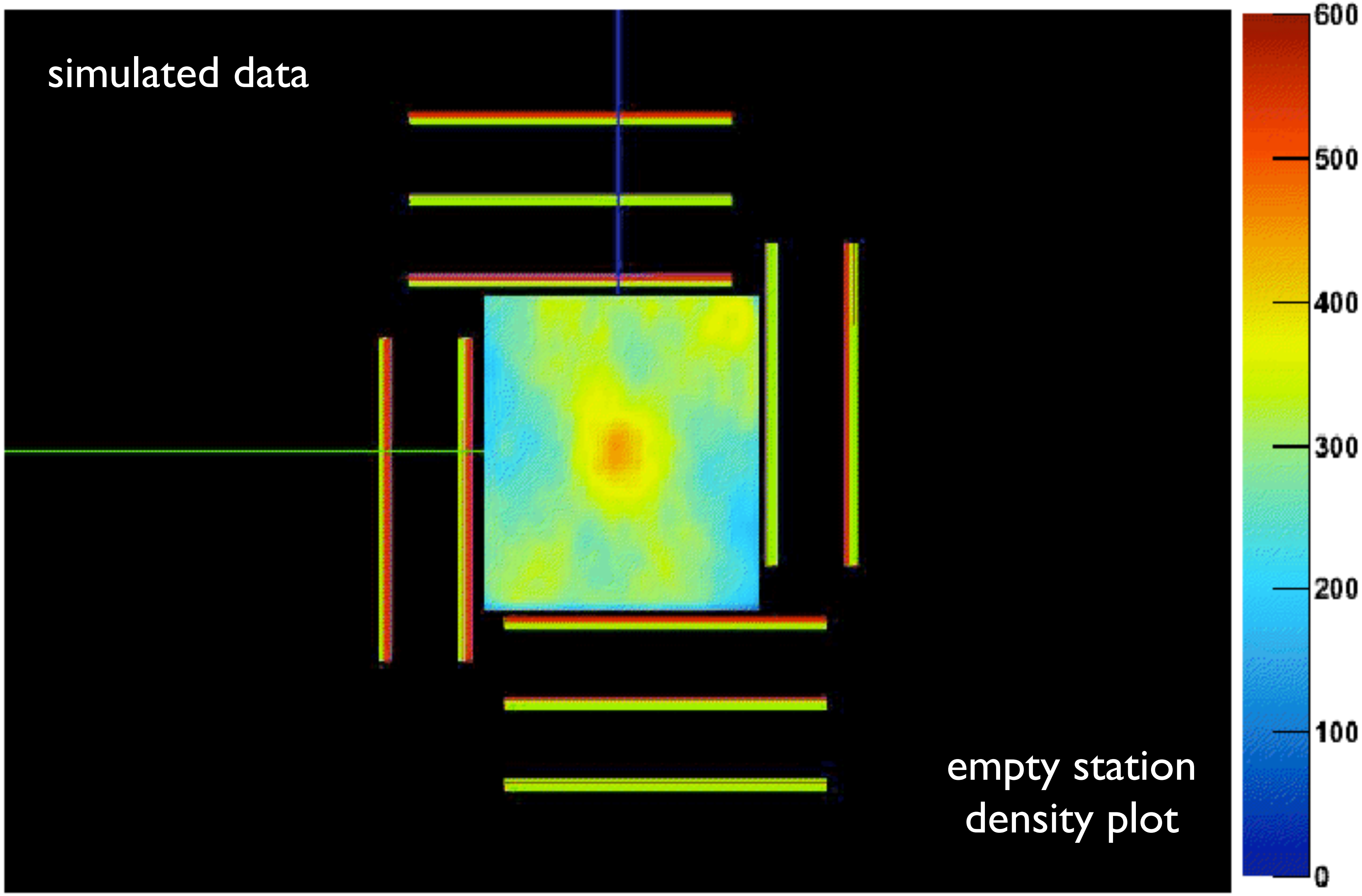


Figure by Nathan Mertins, Florida Tech High Energy Physics Group A

New Approach

- Compare scattering data to the data of an empty station (like "dark-field" calibration)
- Requires normalizing the counts into a density distribution
- Then, the normalized empty data is subtracted from the normalized input scattering data
- Also calculate ratio of average scattering angles - divide the input average angle by the empty scenario average angle

Detection methods

	Description	Strengths	Weaknesses
Maximum scattering density	The higher the value, the more likely high-Z materials are present	Can find small high-Z objects	Weakens with smaller data sets
Average scattering angle	If the ratio of input to empty is above 1.00, high-Z materials are present	--	Won't find small high-Z objects

Findings

5,000 events (~1.5 hrs), box length = 20 mm

	Highest density (normalized and calibrated)	Location of highest count (mm)	Avg scattering angle ratio (degrees)
Five target	0.008	-20, -20, -40	1.15
Lead shield	0.003	-100, -20, 0	1.19
Brass shield	0.004	20, 20, -20	1.24
Empty	0.001	40, -60, -100	0.80

Findings

1,000 events (~20 mins), box length = 20 mm

	Highest density (normalized and calibrated)	Location of highest count (mm)	Avg scattering angle ratio (degrees)
Five target	0.009	-20, -20, -60	1.13
Lead shield	0.005	0, -40, -20	1.11
Brass shield	0.006	20, 20, -20	1.19
Empty	0.003	40, -100, -100	0.75

Findings

500 events (~5 mins), box length = 20 mm

	Highest density (normalized and calibrated)	Location of highest count (mm)	Avg scattering angle ratio (degrees)
Five target	0.010	-60, 20, -40	1.12
Lead shield	0.009	-40, -40, 0	1.14
Brass shield	0.006	0, 0, -60	1.15
Empty	0.008	40, -100, -100	0.77

Findings

100 events (~1 min), box length = 20 mm

	Highest density (normalized and calibrated)	Location of highest count (mm)	Avg scattering angle ratio (degrees)
Five target	0.026	0, 0, -60	1.11
Lead shield	0.029	-100, 20, 0	1.12
Brass shield	0.018	-40, 20, -20	0.82
Empty	0.023	40, 0, -100	0.70

Findings

50 events (~30 secs), box length = 20 mm

	Highest density (normalized and calibrated)	Location of highest count (mm)	Avg scattering angle ratio (degrees)
Five target	0.036	0, 0, -60	1.27
Lead shield	0.039	-40, -40, 0	1.54
Brass shield	0.020	60, 0, 40	0.78
Empty	0.040	-20, -20, 60	0.70

Conclusion

- It is possible to determine the presence of high-Z materials within minutes
- Average scattering angle method worked the best down to 500 events (~5 minutes)
  - Could still function down to 50 events for the cases with large amounts of high-Z materials (five target and lead shield)
- Maximum scattering density method worked down to 1000 events (~20 minutes)

Future steps

- Gather more test data
  - Empty station
  - Scenario where object is off-center
- Keep track of average scattering angle within a region
- Be able to identify the general locations of high-Z materials
- Calculate a probability estimate of presence of high-Z materials

Thank you!

- Questions?